It is somewhat of a question whether it is desirable to maintain a relative humidity as high as 50 per cent in cold weather. Air at a temperature of 74° and a relative humidity of 40 per cent will become saturated when its temperature is reduced to about 48°, and it is not uncommon for the surface of window panes and walls of a room to become that cold when the outside temperature is as low as 0°F. In fact it was noted in making humidity observations in residences that, when the indoor humidity was as high as 50 per cent in cold weather, the windows and even painted walls of rooms were usually dripping with moisture. To pass from a stay in a room this damp into a piercing winter wind is something not many persons care to make a practice of.

The most obvious solution of the problem in the light of the foregoing would seem to be to keep living rooms from being excessively heated, since the difference of a few degrees makes a marked difference in the relative humidity, and to arrange that a reasonable quantity of water be evaporated in the room daily. It would hardly seem to be necessary to state that aridity in sleeping rooms may be entirely avoided by good ventilation and the absence of artificial heat.

551.577 (684.3)

THE PREPARATION OF PRECIPITATION CHARTS.

By WM. GARDNER REED and JOSEPH BURTON KINCER.

[Dated: Climatological Division, June 30, 1917.]

When the preparation of the Atlas of American Agriculture was undertaken by the United States Department of Agriculture, the importance of climate in its relation to agriculture was recognized and a section of the Atlas was very properly devoted to climate. This opportunity was taken to construct a new series of climatic charts with the aid of the data which have been accumulated since the existing maps were drawn. Particularly in the case of precipitation there was an opportunity to construct maps which should depict the conditions more accurately than had heretofore been possible. It seemed proper to review the principles upon which precipitation maps should be drawn and determine how far the data available would permit the construction of maps nearly approaching the ideal. Other climatological maps are now in preparation by the Weather Bureau, and the map of the annual precipitation over the United States was issued in "January, 1917," as "Advance Sheet No. 1: Precipitation" of the Atlas mentioned above.

There is probably no climatic factor concerning which so much has been written as precipitation. From the discussions of the subject it has been possible to formulate a set of rules for the construction of maps which present its distribution graphically.[1]

1. Gage records, except such as have been shown to be in error, e. g., by comparison with neighboring records, should be regarded as the "control" of the map. In spite of the doubts as to whether gage readings agree with the actual precipitation there can be no doubt that these records are the only comparable numerical precipitation data in existence.

2. The data should refer to the same period, which should be as long as possible. This is desirable because of the differences in amount from year to year, and, to be comparable, records must cover the same years. The period selected should be one for which a very considerable number of records are available, because only by the use of many records can the geographical distribution adequately be shown.

3. When these data have been entered on a map there will appear many areas where the course of isohyets drawn to the data will remain in doubt. As there is no convenient artifice for representing "no data," and because the best approximations to the actual conditions in such regions can be made by meteorologists familiar with the data, it seems desirable that the maps should show the probable conditions where records are not sufficient to permit the portrayal of the actual conditions.

To fill these gaps, interpolations are necessary but, unless they be made wisely, the resulting map will not be a true picture of the conditions as they exist. The data upon which interpolations may be made vary greatly, not only in adequacy but in kind. The most useful data for interpolation are gage records covering a portion of the selected period. The precipitation for the whole period may then be deduced from these incomplete records by a comparison with neighboring complete records. Another kind of interpolation is based on analogy; for example, if the precipitation conditions on one mountain range have been determined by adequate gage readings, the same conditions may be inferred on a near-by range of the same elevation and similar exposure, covered with the same or closely allied vegetation and yielding a similar stream flow. Likewise, in the absence of more accurate information, precipitation conditions may be inferred as similar in neighboring valleys of the same mountain group if the elevation of these valleys and their vegetation are similar. Again, differences in vegetation and in the known laws of change in amount of precipitation with altitude, latitude, or distance from the ocean may be of assistance in indicating that a region is wetter or drier than a near-by region in which measurements are available.

In the preparation of a map which shall adequately represent the precipitation of a region, such as the United States, the following should be kept in mind:

1. On account of the great diversity of topography the map must be more or less generalized with the attendant sacrifice of accuracy of detail. In fact, it is probably better to regard any map as a general illustration and to refer to the actual data for detailed information.

2. The "control" of the map should be gage records, covering the same period of years.

3. If complete gage records for the period selected (which should be not less than 20 years) do not exist in sufficient number, the shorter records within the same period should be reduced to the complete period.

4. It must be remembered that in drawing an isohyet from one station to another interpolation is of necessity involved at all points between the stations. Therefore it is well to draw these lines having in mind the topography, the stream flow, and the natural and cultivated vegetation, and to give weight to these conditions in carrying the isohyets from station to station.

5. The object of a precipitation map is to show graphically the distribution of rainfall over the area for which the map is drawn. A map which does not accomplish this is not a good map, and saving clauses such as statements that the precipitation is greater or less than a certain amount should be avoided as far as possible. For example, it is literally correct to mark a region "10 inches plus," where the fall may be 40 inches, but such a practice may be greatly misleading under some condi-

[1] For a collection of expert opinions on the construction of rainfall maps see the MONTHLY WEATHER REVIEW, April, 1902, 30: 205-243, and 2 charts.—EDITOR.

tions. It is self-evident that no precipitation map can be complete in all details; some generalization is necessary, and the extent to which generalization is to be carried is largely a matter of opinion, although the scale of the map and the type of reproduction must be considered.

An examination of the rainfall data of the United States by one of the writers (Kincer) indicated that a large number of records were complete for the 20-year period, 1895–1914. It was therefore decided to adopt this period for the precipitation maps of the Atlas. There were available about 1,600 complete records covering this period and in addition about 2,000 of shorter lengths, from 5 to 19 years, within the same period.

The data from stations with 20-year records were not sufficient to construct a reliable map and so the 2,000 shorter records were employed to supplement them. These latter were reduced to the 20-year period, 1895–1914, by comparing identical years of the nearest stations having records covering the full period. As far as possible comparisons were made by determining the percentage relations between the full 20-year period and the portion of the full record covering the same years as were available for the shorter record. The short record was then corrected by increasing or decreasing its average by the percentage shown when the average for the short period of the 20-year record was compared with the 20-year average. In no case were records of less than five years used as a basis for this type of interpolation. Table 1 shows the method.

TABLE 1.—*Adjustment of the average monthly and annual precipitation at Greenfield, Ind., for the 11-year period from 1904 to 1914, inclusive, to the uniform 20-year period from 1895 to 1914, inclusive, by comparison with records made at Indianapolis and Mauzy, Ind., during the full 20-year period.*

	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Annual.
ELEVEN-YEAR MEANS, 1904–1914.													
(1) Greenfield	3.1	2.6	4.4	3.2	3.8	3.2	3.7	3.4	3.1	3.0	2.6	2.2	38.3
(2) Indianapolis	3.5	2.5	4.5	3.5	3.5	3.1	3.9	3.2	3.0	2.5	2.4	2.3	37.9
(3) Mauzy	3.8	2.8	4.9	3.9	4.1	3.1	3.7	3.8	2.9	3.4	2.2	2.7	41.3
PERCENTAGES FOR THE 11-YEAR PERIOD, 1904–1914.													
(4)=(1)÷(2)	89	104	98	91	109	103	95	106	103	120	108	96	101
(5)=(1)÷(3)	82	93	90	82	93	103	100	89	107	88	118	81	93
20-YEAR MEANS.													
(6) Indianapolis	3.1	2.3	4.3	3.0	3.5	3.2	3.9	3.1	3.3	2.6	3.0	2.6	37.9
(7) Mauzy	3.4	2.6	4.6	3.2	3.9	3.6	3.7	3.4	2.8	2.9	3.0	2.8	39.9
GREENFIELD'S ADJUSTED MEANS.													
(8)=(4×6)	2.8	2.4	4.2	2.7	3.8	3.2	3.7	3.3	3.4	3.1	3.2	2.5	38.3
(9)=(5×7)	2.8	2.4	4.1	2.6	3.6	3.7	3.7	3.0	3.0	2.6	3.5	2.3	37.1
MEANS OF (8) AND (9), OR ADJUSTED MEANS FOR GREENFIELD.													
(10)	2.8	2.4	4.2	2.6	3.7	3.4	3.7	3.2	3.2	2.8	3.4	2.4	37.7

The 20-year averages for the long record stations and the adjusted averages for those of fewer than 20 years were entered on large topographic base maps of the United States, each at its proper location, and lines drawn showing areas of approximately equal precipitation.

Inconsistencies.—In drawing the isohyets the data for a small number of the stations appeared erratic. These cases were examined with great care, and the averages recomputed to detect possible arithmetical errors, but in most cases the original computations were found to be correct. The record was then examined in detail, and this examination usually showed particular years whose records seriously affected the average. In most cases the averages were evidently correct for the data as recorded, and as all the original records had been carefully checked both by the section directors and at the central office the explanation had to be sought elsewhere. In practically all these cases strictly local causes were found which indicated that these records were not truly representative of large areas, and it became necessary either to disregard them or to show small areas of precipitation different from the surrounding regions. As it is believed that a map of an area as large as the United States should depict mainly general conditions, it appeared better in most cases to disregard the erratic averages rather than to attempt to show small areas with precipitation markedly different from the surrounding regions.

To meet the demands of those desiring rainfall statistics the meteorologists responsible for the collection of such data are required to prepare maps showing the different amounts of rainfall for widely extended regions, which will inevitably embrace large areas for which no data are available, because it is impracticable and in many cases impossible to get gage records in areas like the unpopulated mountainous regions of the western United States, where the very few inhabitants are all located in the valleys, avoiding the mountains and other inaccessible places. In these regions direct observations of rainfall are therefore unattainable, not only because of the lack of funds but because there are no means of securing records of precipitation, through no fault of those responsible for the collection of statistics.

The best procedure in attempting to depict rainfall in regions where no observations have been obtained is a matter of debate and difference of opinion. In the maps employed in ordinary cases the unreported regions in question can not be entirely omitted because, as previously stated, there is no convenient artifice by which to indicate that the precipitation is not known in certain regions and that the amount we decide to indicate on the map may not be the correct amount. In many cases, also, the needs of the user of the map require that the best estimate of the rainfall be shown. The practice adopted for such regions depends to a considerable extent upon the use to which the map is to be put, the personality of the author of the map, and the limitations under which it is made. For example, much has been learned not only of the relation between rainfall and elevations, but studies in various parts of the country have shown how far the same types of vegetation are possible in different regions. In addition, it is clear that the best map of precipitation will be drawn when the compiler has in mind not only gage records but also all the other information available, whether quantitative or merely qualitative. The most useful rainfall map is that which gives the best picture of the actual conditions.

The relation between climatic factors and vegetation is exceedingly complex and, while it is perhaps generally true that the existence of a forested region indicates more rain than falls on near-by unforested areas, conditions of temperature and humidity, which can not safely be neglected, may account for all the differences observed.

The relations between rainfall and run-off have been studied in several localities in the United States, and while no general law has been determined it is obvious that in the long run no more water can be carried by the streams than falls on the watershed; and when two similar watersheds have similar stream discharges it is reasonably safe to assume they receive similar amounts of precipitation.

Some phases of the relation between rainfall and altitude are now known, but as a general rule precipitation increases with altitude *up to a limiting elevation;* the altitude of heaviest precipitation, however, is not well known and probably is not the same in different regions. Slope and direction of winds are also factors which must be considered. In the Sierra Nevada the zone of maximum rainfall occurs at an altitude varying from 4,000 to 6,000 feet.[2] This range presents a practically unbroken ridge extending across the path of the prevailing winds which blow directly from the ocean, and is therefore a very simple case. The relations are far from clear with more irregular mountain masses, especially such as are situated at some distance from the ocean, particularly those where the winds must cross considerable altitudes before reaching the mountains under consideration.

Perhaps the most important relation existing between topography and rainfall is the occurrence of "topographic barriers." In the absence of definite information to the contrary, it is not safe to assume that similar conditions exist in regions separated by mountain ranges. The practical difficulty is increased by the fact that it is nearly as unsafe to assume that different conditions exist on different sides of a mountain range. A mountain range usually limits the conditions, but this limitation does not mean that the conditions at given levels are not the same on both sides.

As long as the precipitation is stated in terms of depth of water, it is essential that the maps be based on gage measurements. It may be practicable to construct a map in terms of vegetation; from bare desert through sage brush desert, grassland, scattered trees, etc., up to dense forest. Such a map would be very useful and not misleading if its basis were properly explained; but the attempt to translate such data into terms of depth of water necessarily involves assumptions which are not fully warranted in the present state of our knowledge. In the preparation of rainfall maps many conditions arise which must be decided more or less arbitrarily, although the decisions should be consistent among themselves. For example, the oft-cited case of Mount Washington may be considered. In this case there is no doubt that the precipitation on the summit is nearly double that of the surrounding region below. The mountain, even if the whole Presidential Range be included, covers so small an area that it is hardly more than a dot on any moderate sized map of the United States. The result is that the area of heavier fall must be exaggerated in size or ignored, unless the somewhat objectionable expedient of printing the figures on the map be adopted. Such areas may be omitted on the ground that there are doubtless other similar places without data, but this does not seem to be good practice, as precipitation data are scanty enough at best and all authentic records are needed to bring out the actual conditions. A similar situation exists in the case of small valleys surrounded by higher lands. Attempts to construct an adequate precipitation map of the western highland of the United States meet great difficulties. Considerable of the region is largely higher than the altitude of maximum precipitation in the Sierra Nevada, the topography is imperfectly known, the forest areas have been mapped liberally to say the least, the region is more or less arid with the resulting wide variations in precipitation both from time to time and from place to place, and finally the habitations and hence the rain gages are frequently located in places which are not typical of the area, if any typical places can be said to exist. The mountains to be sure, in some parts of the region, have heavier vegetation and greater run-off than the near-by valleys; but they are also regions of lower temperature and smaller exposed ground surface which, especially in a region of strong insolation, makes a vast difference in evaporation. The mountains may be regions of heavier precipitation than the neighboring lower levels, and they may not. In such cases of doubt it seems better that the isohyets be broadly generalized on the basis of the gage records and a statement made that the precipitation may vary locally in either direction from the amount indicated.

It is not practicable to carry on the map more information than the precipitation data, the topography, and enough "culture" to permit accurate location of places and of regions. There is, however, an enormous mass of additional information much of which is not subject to exact statement at present, which may assist in the location of isohyets between stations. The simplest of such cases is that of two regions separated by high mountains; here it is manifestly proper to carry the line around rather than over the mountains. In the western part of the country such cases arise continually. Certain mountain areas are known to be regions of heavy snowfall, particular valleys are known to be drier than the surrounding mountains, certain areas have climates which will or will not support certain natural vegetation or which will permit or prevent certain types of agriculture. All this information, while distinctly subordinate to gage records, helps to show on which side of the area the isohyet should be drawn. A gage record on one mountain mass will give an indication of the probable rainfall conditions of an adjacent area of similar topography and location where there is no record, and records for one portion of a plateau area suggests the conditions of other parts for which no records are available. It is essential, however, that such inferences be made with caution and careful consideration of all the information which has any bearing at all on the subject.

[2] *A. J. Henry* in MONTHLY WEATHER REVIEW, April, 1902, 30: 208.